Feasibility of storing canola at different moisture contents in silo bags under Canadian Prairie conditions

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Canola is the major oilseed crop grown in Canada and the canola industry contributes nearly 15.4 billion dollars annually to the Canadian economy (CCC 2013). The annual average production of canola in Canada is 9.4 million tonne (StatsCanada 2013). The prairie region (Manitoba, Saskatchewan and Alberta provinces) accounts for nearly 99% of total area of canola production in Canada (StatsCanada 2013). The recommended moisture content (m.c.) for storage of canola seeds is 10% (Mills, 1996). Numerous challenges occur during harvest and storage of canola due to the small size of the seeds (Ochandio et al. 2010a). Respiration rate of freshly harvested canola seeds is high, resulting in large production of carbon dioxide (CO2) and heat (Mills 1996). Following harvest, 6 weeks are required to reduce respiration, and then seeds enter a quasi-dormant stage (Thomas 1984). If canola is harvested at more than 10% m.c., it will spoil rapidly, therefore, it is recommended to
The accumulation of moisture due to condensation inside the bag storage system. This proportion of the bulk seed is held at the surface during storage (Darby and Caddick 2007), a high season. When compared to other vertical or horizontal storage systems (Darby and Caddick 2007), a high proportion of the bulk seed is held at the surface (peripheral) layer of the bag storage system. This peripheral layer undergoes large temperature and moisture changes during storage (Gaston et al. 2009). Large temperature gradients may cause moisture migration, and the accumulation of moisture due to condensation inside the harvest bag can cause localized seed spoilage. Jian et al. (2015) found accumulation of condensed water inside the grain bags is a common problem under western Canadian climatic conditions. Darby and Caddick (2007) also found accumulation of condensed moisture in silo bags stored under Australian weather conditions and they also found more than 18% of the stored bulk in silo bags had some quality reduction. Seed moisture and temperature during storage play a major role in determining safe storage durations (Sathya et al. 2009; Nithya et al. 2011) in any storage structure. Grain germination and free fatty acid value (FAV) are the main quality parameters used to determine the quality of the grain during storage. Seed temperature and moisture content can change during storage. Carbon dioxide concentration of intergranular air can be used as an indicator of grain quality (White et al. 1982). Therefore, the objective of this study was to determine the feasibility of using silo bags to store canola at three moisture contents under Canadian prairie conditions by monitoring changes in seed quality (germination and FAV), intergranular gas concentration and seed temperature. The three nominal initial moisture contents tested were: 8, 10 and 14%, representing dry, straight and damp moisture of canola, respectively.

MATERIALS AND METHODS

Canola

Canola seed was obtained from a commercial elevator (Richardson International Limited, Dauphin, Manitoba) at three different moisture contents (nominally: 8, 10, and 14%) and loaded into grain bags on October 7-8, 2010 using a bag loader (Fig. 1). The bags were 2.74 m diameter with 238 µm polyethylene membrane thickness (Manufacturer: IpesaSilo, Ciudadela, Argentina). During loading with the canola seeds, these bags stretched up to 10% of their diameter. The moisture content was considered as an experimental treatment, and each treatment had three replicates. The canola seeds were

![Fig. 1. Loading of canola seeds into silo bags (A) and silo bags with sampling arrangement (B) Inset the picture, (i) seed sampling ports, (ii) CO₂ sampling tubes, and (iii) thermocouples.](image-url)
loaded in nine silo bags (3 treatments × 3 replications) with approximately 20 t of canola seed per bag, and stored until August 10, 2011.

**Grain quality evaluation**

**Sample collection** Samples were collected through seed sampling ports at the center along the length of the bag (Fig. 2 (A)). Seed sampling ports were created by placing PVC nipples with bulkhead fittings into the bags (Fig. 1(B)). These nipples were closed at the end with caps and the cuts made for inserting these fittings were closed using tape (specially designed for silo bag by IpesaSilo, Ciudadela, Argentina) and expansion Styrofoam (Great Stuff Gaps & Cracks, The Dow Chemical Company, Midland, MI). Once every 2 wk, seed samples were collected using a grain trier (standard grain probe (Fig. 2 (C)) (1.83 m length brass probe with 10 openings, Model: 16-OH, Seedburo Equipment Company, Des Plaines, IL). Seed samples were collected from 0.15, 0.8 and 1.35 m from the top of the bag, which represent the top, middle and bottom layers of the silo bag (marked with ΔS in Fig. 2 (B)). Seven samples were collected from each bag. Four samples of the total seven samples represented middle (S1

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**Fig. 2.** Overhead (A), cross sectional (B) view of sampling locations and (C) grain sampling probe. In the graph, Δ - seed sampling locations; • - temperature measurement locations and CO₂ collection locations.
Tukey’s method showed that, there were no significant differences in quality parameters among samples collected from side and center ports. So samples were clustered into three groups: top, middle and bottom. These three groups represented the layers of seeds inside the silo bags. Temperature and CO₂ locations were also clustered into these three groups. A three-factorial design model (moisture content, storage time and sample location) was used for ANOVA test and SAS 9.3 software was used for statistical analysis (SAS 2012). The moisture contents used in factorial design were the three initial moisture contents of the canola seed (dry, straight, and damp), and the sample locations were the top, middle and bottom layers.

Moisture and temperature profiles of the canola inside the silo bags were plotted using SURFER software (Version 12, Golden Software Inc, Golden, Colorado) (Surfer 2012). Noon temperatures of canola at top, middle, and bottom layers of silo bags on October 10, 2010, January 15, 2011, May 1, 2011 and July 31, 2011 were used as input for creating temperature profiles of fall, winter, spring, and summer seasons, respectively. Moisture content of canola at top, middle and bottom layers of silo bag at week 0, 14, 28, and 40 were used as inputs for creating moisture profile plots in fall, winter, spring, and summer seasons, respectively.

RESULTS

Grain quality

Moisture Content The initial moisture contents of canola seeds delivered from the elevator were 8.9±0.2% (referred to as dry moisture bag), 10.5±0.3% (referred to as straight moisture bag), and 14.4±0.1% (referred to as damp moisture bag). In dry moisture bags, the moisture content of the canola seeds at the top layer was higher than that at middle and bottom layers of bags up to 28 weeks of storage (Fig. 3). In dry moisture bags, the moisture gradient at different parts of the bags stayed within one percentage point throughout the storage periods, but damp moisture bags experienced larger moisture gradients, especially after 28 weeks of storage. The storage initial moisture and storage time and sampling location had significant effect ($p<0.008$) on changes in moisture content inside the silo bags during storage. There was no significant difference in moisture content between top and middle layers of the bag ($\alpha=0.05$), but there were significant differences between top and bottom, as well as middle and bottom layers of the bag due to moisture migration inside the silo bags.

Germination In dry moisture bags, germination of the seeds at all sampling locations was more than 90% of initial germination even at end (40 wk) of the storage (Fig. 4). The seed germination was more than 80% of initial germination at all sampling locations, except three locations near the top of the straight moisture bag. Germination of canola seeds in dry and straight moisture canola bags was always higher than that of damp moisture canola bags, except the top portion of the straight moisture canola bags. Germination of seed decreased with increased
storage time in damp moisture bags, and germination in damp moisture bags decreased below 50% of initial germination at top and bottom parts of the damp moisture bags after 16 wk of storage. The temperature profile graphs (Fig. 13) clearly show a localized hotspot at the middle portion of a bag in damp moisture bags, which correlate with the decreased in germination at that location. All the individual factors and their interactions had significant effects ($p<0.001$) in change in germination of canola seeds. Means comparisons test showed that, there were no significant changes in germination of dry canola seeds up to 32 weeks of storage, but the germination of canola was significantly affected after 12 weeks of storage in damp canola bags ($p<0.001$). Germination at the top layer of canola seeds in silo bags was significantly lowered from the middle and bottom layers of canola seeds in straight and damp canola bags.

Fig. 3. Moisture content of canola seed at different layers of silo bags during storage. The moisture contents showed in the legends are the initial moisture content (Loading: Oct 7-8, 2010; Unloading: Aug 10, 2011).

Fig. 4. Germination of canola seed at different layers of silo bags during storage (Loading: Oct 7-8, 2010; Unloading: Aug 10, 2011).
Free Fatty Acid Values  

Initial FAV values of dry, straight and damp moisture canola were 23.2, 23.5, and 25.2 mg KOH/100 g, respectively and increased to 25.9, 35.0, and 41.2 mg KOH/100 g, respectively, after 28 wk of storage (Fig. 5). After 40 wk of storage in silo bags, the FAV values were 26.9, 32.9, and 50.0 mg KOH/100 g for dry, straight, and damp moisture canola, respectively. The FAV value of the damp canola increased more than 1.5 times the initial value after 8 wk of storage in silo bags. In straight moisture bags, FAV values were higher near the top of bags and correlated with the high moisture seeds near the top of bags. The storage time, storage moisture and their interactions had significant effects (p<0.005) on FAV values, but the sampling location had no significant effect (p=0.171) on changes in FAV. There was no significant change in FAV of dry canola seeds throughout the storage time, but in 14% m.c. canola bags, it increased significantly after 8 weeks of storage. In straight moisture canola seeds, there was significant difference between FAV value at the start and 8 weeks of storage, but there were no significant differences between 8 and 40 weeks of storage.
Intergranular CO\(_2\) concentration and grain temperature

**Carbon dioxide concentrations** The CO\(_2\) concentrations of dry, straight and damp moisture canola bags were 3.6-4.0, 7.5-9.4, and 19.0-20.9\%, respectively, after 4 wk of storage (Fig. 6). The higher CO\(_2\) concentrations in damp moisture canola bag were probably due to the high amount of biological activity in the wet seed bulk. After 40 weeks of storage, CO\(_2\) concentrations were 1.3\% or less in the two dryer bags and above 2.9\% in the damp canola bags. The storage moisture and storage time had significant effects (p<0.001) on changes in CO\(_2\) concentrations, but the sampling location did not (p=0.542). The interaction between storage moisture and storage time also showed significant effects (p<0.001) on CO\(_2\) concentration changes. Some perforations made by rodents in all three moisture content bags were found during unloading, which may be the reason for drop in CO\(_2\) concentrations after 8 weeks of storage.

**Temperature** In dry and straight moisture canola bags, seed temperature near the bottom of bags was higher than other parts of the bag during autumn and winter, and seed near the top of bags was hotter than other parts of the bags during spring and summer time (Fig. 7). Seed temperature of the top layer followed the ambient temperature changes, and most of the storage period temperature difference between bottom and top layers was about 15\°C. Temperature pattern of damp moisture canola bags was different than the other two drier canola bags, and hotspots developed inside the damp moisture canola bags could be the reason for this change in temperature pattern. Even in mid-winter, the temperature of top layer of the damp moisture canola bags stayed above freezing, and the middle layer of the canola seeds followed the ambient temperature during winter time.

**Moisture and temperature profiles**

The moisture migration inside the bags due to temperature gradients between the top and bottom layers of the grain profile was noticed in all three moisture content canola
bags from the moisture profile graphs (Figs. 8-10). In winter, the moisture contents of top layer of silo bags were 9.5, 12.2, and 15.6% in dry, straight and damp moisture content silo bags, respectively, but in summer, the top layer moisture contents were 7.9, 9.8, and 13.5%, respectively.

The temperature profile graphs show that temperature of the bottom layer of the grain was 4°C on January 15, 2011, and at the same time the temperature of the top layer of canola was -13°C (Figs. 11-13). This trend was the same in all three moisture content canola bags. These temperature profile graphs clearly showing the trend of top layer following the ambient temperature changes, and temperature difference between bottom and top layers were greater than 10°C for most part of storage in all 3 moisture contents. The temperature profile map also shows a hot spot in the damp moisture canola bag, which might be the reason for caking (seeds clumping together due to moulding and heating) of canola.

**Commercial grading of canola**

All three moisture content canola seeds were graded as Canada Grade 1 at the beginning of the experiment. After 40 wk of storage, dry and straight moisture content canola seeds were graded as Canada Grade 1, and Canada Grade 2, respectively. Small amount of heated seeds were found in the top layer of straight grade canola bags, which reduced the grade. The damp grade canola seeds were caked due to the high moisture and the grain bag extractor could not be used to unload the canola seeds (Fig. 14). The canola seeds in damp grade bags were graded as Feed Grade.

Fig. 9. Moisture profile of silo bag with straight moisture content canola in (A) Fall, (B) Winter, (C) Spring, and (D) Summer seasons.

Fig. 10. Moisture profile of silo bag with damp moisture content canola in (A) Fall, (B) Winter, (C) Spring, and (D) Summer seasons.
DISCUSSION

Our results show that seed moisture plays the major role in the deterioration of canola during storage. Previous studies also found that storage moisture and duration are the main parameters in determining safe storage conditions for canola and other grains (Bartosik et al. 2008; Sathya et al. 2009; Sun et al. 2014). According to safe storage guidelines of canola developed by Sathya et al. (2009), storage conditions can be considered safe for canola storage if germination stays >80% of the initial germination. In our study, the dry moisture canola had more than 90% of initial germination throughout the 40 weeks of storage in silo bags. The increase in FAV content is the direct reflection of the deterioration of stored products (White and Jayas 1991), and FAV has positive correlation with the storage moisture (Sathya et al. 2009). An increase of FAV by 1.5- fold of initial values was used as a threshold for deterioration of rapeseed (White and Jayas 1991). In our study, the FAV of canola seeds increased more than 2-fold the initial value in damp moisture canola bags, but the increase was less than 1.5- fold in dry and straight moisture canola bags. The germination dropped and FAV increased with damp moisture canola with hotspots and caking occurring. Christensen and Kaufmann (1969) reported that production of free fatty acids is directly proportional to the moisture content of the seeds and fungal activity. The lower FAV values of the dry moisture content canola bags indicate less biological activity in dry seeds.
The maximum CO$_2$ concentrations in dry, straight and damp canola bags were 4.0, 9.4, and 20.9%, respectively, after 4 wk of storage. Canola has a high respiration rate for up to 6 weeks after harvest (Thomas 1984). This may be the reason for the high concentrations of CO$_2$ in the first 8 weeks. Ochandio et al. (2010a) also found the same trend in CO$_2$ concentrations of canola seeds stored in silo bags under Argentinian weather conditions. Bartosik et al. (2008) found that storing wet grains in silo bags created a favorable environment for mold growth and led to an increase in CO$_2$ and a decrease in O$_2$ concentrations. The mold development in grain reduced the grain quality. Barreto et al. (2013) analysed the quality changes of wheat in silo bags at three different climatic (sub-tropical, intermediate and temperate) conditions in Argentina using mathematical modelling. Their results showed that increase in CO$_2$ concentration and depletion of O$_2$ inside the silo bags were mainly depended on initial grain temperature and moisture content.

The moisture and temperature profile graphs indicate the moisture migration between top and bottom layers of the canola due to the temperature gradient. In winter, hot and humid air from the bottom of the bag moved up and got condensed at the top of the bag, which caused the increase in moisture at the top layer of the bags. This trend was similar in all three moisture content canola silo bags. The increase in moisture at the top layer might have caused the localized hot spots, which might lead to fungal growth in damp moisture canola bags, once the temperature of the grain increased to favourable conditions during spring and summer. Even though in summer, the top layer of the grain dried up due to the moisture movement cycle and was in the opposite direction (from top layer to bottom), the hot spots developed during winter due to heating and moulding might have caused the spoilage of grain at the peripheral layer of the bag in damp moisture canola bags. Temperature data also showed that, the damp canola in silo bags had different temperature pattern due to moulding and heating than the dry and straight moisture canola. This is similar to other studies. Barreto et al. (2013) found a slight increase of moisture content at the top layer of the bags filled with wet grains (16% m.c.) where the equilibrium relative humidity was above the safe storage levels throughout the storage period (even in colder months). Gaston et al. (2009) noticed a rise in wheat moisture content at the top layer of silo bags, and they concluded that the temperature gradients between top and other parts of the bag caused the moisture migration to the top layer of the bag. Jian et al. (2015) found this was mainly caused by condensation of migrated moisture. When compared with storage of grain in bins, a larger amount of seed is located at the periphery of the storage structure in a silo bag. So the temperature and moisture changes were large during storage, especially under the Canadian Prairie conditions, where temperature
differences between winter and summer is about 60°C (-30°C in winter and 30°C in summer). These large temperature fluctuations also lead to condensation at the top of bags (Jian et al. 2015). Bartosik (2008) recommends that dry (below 76% ERH) grains (wheat, soybean, barley, corn, canola, and sunflower) can be stored for more than six months without any quality deterioration. Our data support with this recommendation.

CONCLUSIONS

The germination and FAV of dry moisture canola seeds stayed at an acceptable quality level and there was no change in commercial grade for up to 40 weeks of storage in silo bags. Germination of straight moisture canola stayed at safe levels in most parts of the silo bags, but the germination dropped to below 80% of its initial germination in the top layer of the silo bags. The commercial grade of the straight moisture canola was downgraded by one grade after 40 weeks of storage. Inside the damp moisture bags, the germination dropped below safe storage levels and FAV increased twice of its initial value within 8 weeks of storage. Dry (8% m.c.), straight (10% m.c.), and damp (14% m.c.) canola seeds can be stored up to 40, 24, and 4 weeks, respectively after harvest without any quality loss under Canadian prairie conditions.

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